+

CONTENTS

Chapter 1 Introduction 2

Chapter 2 Literature Review 5

Chapter 3 Objectives 8

Chapter 4 Methodology 10

4.1.1. Research procedure to develop an optimal Millimeter wave MIMO channel estimation solution for sparse nature of the millimter wave channel.....

4.1.2. Research procedure to develop optimal precoder/combiner design for multi-user Millimeter wave MIMO system.....

4.1.3. Research procedure to develop an optimal Millimeter wave MIMO channel estimation solution for multi-cell multi-user scenario .....

4.1.4. Research procedure for performance of Nonorthogonal multiple access in Millimeter Wave communication.....

4.2. Tools..... .....

References 12

CHAPTER 1
INTRODUCTION

Mobile communication and internet data used in wireless communication in 2016 were 0.6 ZB. Cisco predicted that by the year 2021 total traffic will reach up to 2.5 ZB per year [1]. Mobile internet usage for 4k video streaming and other purpose is growing annually at 68%. To fulfil this high data requirement by 2021 efficient implementation of physical layer techniques are required [2].

In order to enhance the capacity and performance of 4^{th} generation mobile communication, 3GPP and IEEE are going to introduce standardized 5^{th} generation wireless system by the year 2020 [3, 4]. In general, 5^{th} generation wireless system supports internet of things, device to device communication, machine to machine communication and high density of broadband cellular user [5]. Table1.1 indicates the main requirements of 5^{th} generation mobile communication with respect to the currently used 4^{th} generation systems [6]. To meet the 5^{th} generation requirements, three techniques, i.e. deployment of ultra dense network, allocation of new spectrum band and enhance spectrum efficiency can be applied in reality to improve the performance of current 4th generation system [7,8,9]. The overall 5^{th} generation aims to improve wireless data rates, spectral bandwidth, coverage area, device connectivity, maximizing the energy efficiency and reducing the round trip delay up to 1ms.

Table1.1 Performance comparison of 4^{th} Generation and 5^{th} generation network [1]

Performance Metrics	**5G**	**4G**
Peak Data Rate (Gbps)	20	1
User experienced data rate (Mbps)	100	10
Spectrum efficiency(bit/s/Hz)	3×	1×
Mobility(km/h)	500	350
Latency(ms)	1	10
Connection density(devices/km^2)	10×	1×
Network energy efficiency	100×	1×
Area traffic capacity (Mbit/s/m^2)	10	0.1

New physical layer technologies such as Millimeter wave (mmWave) communication, Massive multiple input multiple output (MIMO), Full duplex, Filter bank multi carrier, cognitive radio, cooperative communication and Non-orthogonal multiple access (NOMA) are expected to be used in 5^{th} generation mobile communication. Millimeter wave communication is operating in band of 28 GHz-300GHz as shown in Fig.1. Signal processing in transmitter and receiver at Millimeter Wave is different than currently used in microwave frequency. Effective implementation of beamforming and MIMO techniques are required in order to improve the system performance of wireless communication in Millimeter Wave [10].

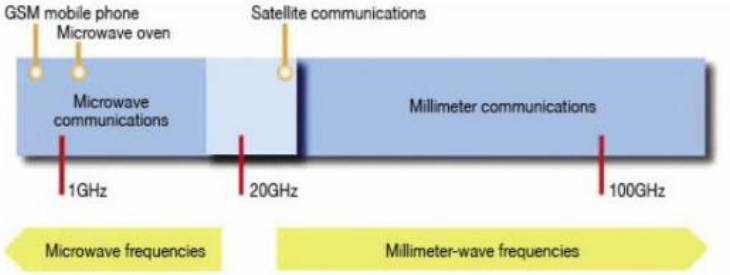

Figure 1: Communication in millimetre wave frequency (Image Courtesy: B. Manikandan, P.J. Phavithra, S. Vinodhini & R. Darwin, 2018)

The taxonomy about Millimeter Wave communications is shown in Fig. 2. Research in Millimeter Wave communication is further classified in to physical layer, MAC layer, network layer and other available resources [11]. To enhance the network capacity, coverage area and high gain, lot of research work is required in physical layer in the area of modulation mode, MIMO, channel model, precoding, antenna array design, physical layer security, design of circuit components and NOMA.

The aim of precoding is transmitting the pencil shaped beams that point directly at desired user terminal with minimal or no interference at unintended user equipment side. Precoding is classified in three ways: digital precoding, analog beamforming and hybrid beamforming. Hybrid beamforming is promising technique for Millimeter Wave MIMO communication as it maximizes the achievable rate [12]. NOMA with Millimeter Wave is new access technique to improve the significant channel capacity by allowing multiple UE (user equipment) to share same resources compared to orthogonal multiple access.

Therefore optimization of physical layer techniques for Millimeter Wave communication is research hotspot, so as to improve the overall gain and extend coverage area.

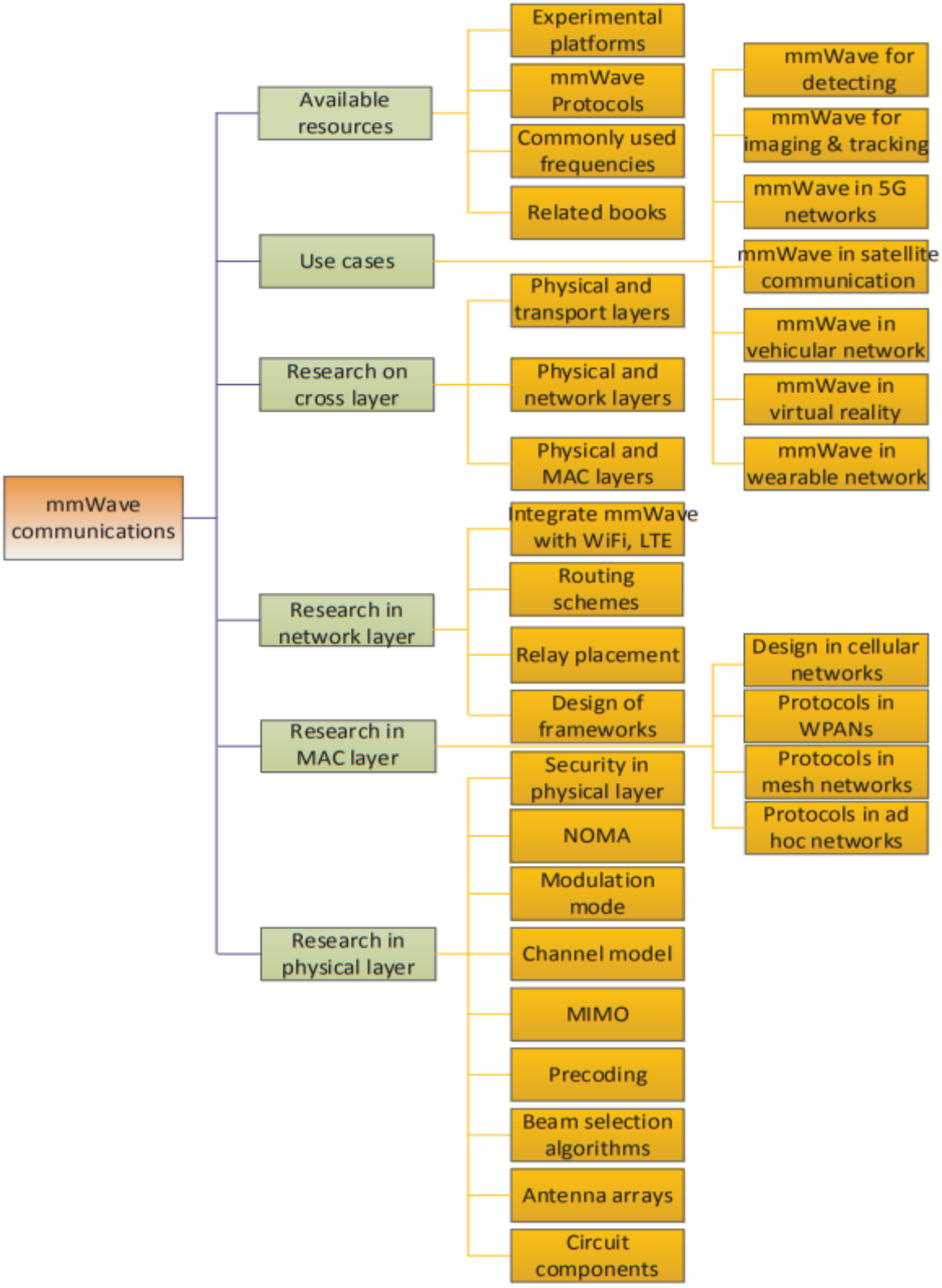

Figure 2: Millimeter Wave communication taxonomy (Image courtesy: X. Wang, L. Kong, F. Kong, F. Qiu, M. Xia, S. Arnon & G. Chen, 2018)

CHAPTER 2
LITERATURE REVIEW

- A. Alkhateeb et al. (2015), discussed on limited feedback hybrid precoding for multiuser Millimeter wave MIMO system. This work is further extend to develop efficient Millimetre Wave precoding and channel estimation algorithm for multiuser cellular system taking in to consideration the inter cell interference.

- L. Dai et al.(2015), described NOMA and orthogonal multiple access schemes coexist in a system and different types of devices in the network can use the different part of the spectrum using the multiple access technique that would be the best fit for them. For example, the Internet of things device can use Generalized Frequency Division Multiplexing (GFDM) with a long cyclic prefix while the mobile device streaming video can use some orthogonal multiple access scheme that supports high data rates and the schemes to use can be configured adaptively based on the user requirement and the load on the base station.

- J. Jing et al. (2016), presented hybrid beamforming design of multi user Millimeter Wave MIMO scenario in order to maximize the energy efficiency of downlink system.

- R. W. Heath et al. (2016) proposed the signal processing techniques in Millimeter wave communication system. MIMO architecture at Millimeter wave is completely different than at sub 6 GHz. At microwave frequencies signal processing happens in baseband where as Millimeter Wave support hybrid architectures with baseband precoding and RF precoding at transmitter side and RF combining and baseband combining at receiver side.

- T.E. Bogale et al. (2016), discussed channel estimation algorithm on fully digital TDD massive MIMO system operating in microwave frequency. However these algorithms cannot be directly applied to hybrid Millimeter wave

system as the number of RF chain is much smaller than the number of antennas. In fact, for the channel estimation in hybrid millimetre Wave system, the strategies of allocating analog/digital beams to different users and estimating the equivalent baseband channels are still an open area of research.

- J. Lee et al. (2016), proposed channel estimation for sparse Millimeter Wave channel and formulating the channel model based on parameters angle of arrival, angle of departure, delay, complex gain, and Doppler shift. The Doppler shift arises due to the relative motion of transmitter or receiver and it can be calculated by the angle of arrival or departure. The problem formulated is further solved by applying the orthogonal matching pursuit.

- S. A. R. Naqvi et al. (2016) proposed both NOMA and Millmeter Wave techniques to optimize the usage of a cellular network's resources, as opposed to network using OMA (orthogonal multiple access) and UHF technologies.

- L. Zhao et al. (2017), implemented channel estimation algorithm for sparse and non sparse Millimeter Wave channel. Assuming perfect channel estimation and calculate the performance of system for low and high SNR regime. The average achievable rate for proposed scheme is observed with ZF precoder.

- A. S. Marcano et al. (2017) presented the implementation of Millimeter wave with NOMA. Analysing the capacity gain considering the signal to interference plus noise ratio and comparing the performance using OMA (orthogonal multiple access).

- D. Zhang et al. (2017) proposed integrated model of Millimeter wave with NOMA. To simplify the channel capacity analysis, integrated model is observed for low SNR regime and high SNR regime.

- L. Zhao et al. (2018), proposed multi cell Millimeter Wave hybrid system and apply the channel estimation over rician fading channel. Channel estimation algorithm for single cell, mention in above step is applied to multi cell scenario in order to observe the system performance by considering the impact of channel contamination.

.

- J. P. Coma et al. (2018) proposed frequency selective wideband Millimeter Wave channel and design consideration of precoder and combiner for multiuser hybrid Millimeter Wave system.

- X. Wang et al. (2018) presented survey in Millmeter communication considering the research in physical layer, cross layer, MAC layer and other areas. In physical layer further research direction are indoor and outdoor channel model, MIMO, precoding, LOS component, circuit component issues, modulation mode (OFDM, FBMC, GFDM, UFMC), NOMA and physical layer security.

- U. S. S. S. Arachchillage et al.(2018), offered comparative features on demonstrating how NOMA impacts device to device (D2D) communications, cognitive radio networks, massive multiple input multiple output (MIMO), radio frequency (RF) energy harvesting, and other emerging technologies in 5G.

Rationale:

The Millimeter wave band (28 GHz-300GHz) offers higher bandwidth communication and support higher data rates than currently used in sub-6GHz band. Signal processing is challenging in Millimeter wave MIMO system. There are several important differences with respect to sub-6GHz communication, resulting in new constraints on the hardware. Key hardware challenges are

1. High carrier frequency and bandwidth of communication channels.
2. Signal propagation and channel behaviour are different in the mmWave band.
3. Large arrays are used at both the transmitter and receivers due to smaller wavelength.

Thus, novel technology solutions are required to overcome hardware constraints, channel models and signal processing with large arrays. These will have significant impact on the design and implementation of Millimeter wave communication system.

CHAPTER 3
OBJECTIVES

1. **To develop an optimal Millimeter wave MIMO channel estimation solution for sparse nature of the millimetre Wave channels.**

   Millimeter wave MIMO channel model have fewer and clustered paths and more sparsity in the channel because of extremely short wavelength compared to sub-6GHz frequency band. The number of RF chain requirement in hybrid Millimeter wave system is much smaller than the number of antenna used in communication. Therefore existing sub- 6GHz channel estimation algorithm cannot be directly applied in Millimeter wave system.

2. **To develop optimal precoder/combiner design for multi-user Millimeter wave MIMO system.**

   There are very important differences between MIMO architecture at sub- 6GHz frequencies and at Millimeter wave frequencies. At lower frequencies the entire signal processing action happens in the baseband while in Millimeter wave due to several hardware restrictions, signal processing is accomplished in a mixture of analog and digital domain. Hybrid analog – digital precoding and combining is novel approach for low complexity implementation of MIMO in Millimeter wave system.

3. **To develop an optimal Millimeter wave MIMO channel estimation solution for multi-cell multi-user scenario.**

   In multi-cell multi user scenario it is necessary to analyze the inter cell and intra-cell interference during the uplink/downlink transmission. In order to suppress the interference, it is required to develop the optimal Millimeter wave MIMO channel estimation solution for multi cell communication system.

4. **To investigate the performance of Non-orthogonal multiple access (NOMA) in Millimeter wave communication.**

In NOMA, multiple users can be served on the downlink or can transmit on the uplink at the same time/code/frequency but with different power levels. NOMA yields a throughput larger than OMA (Orthogonal Multiple Access). Recent analysis have been evaluated for the performance of Millimeter wave and NOMA techniques individually. However the combination of implementation of both techniques needs to be further evaluated for 5G network.

CHAPTER 4
METHODOLOGY

4.1. **Research Procedure**: There are following proposed research procedure to achieve the satisfactory fulfilment of the above objectives

4.1.1 Research procedure for optimal Millimeter wave MIMO channel estimation exploiting the sparse nature of the Millimeter Wave channels

Modeling and simulation of various channel estimation methods on hybrid mmWave systems using tools like MATLAB and NS-3 shall be done so as to develop and propose optimum channel estimation techniques for improving the performance of the system. Result of existing and proposed work shall be compared to draw conclusive references.

4.1.2 Research procedure to develop optimal precoder/combiner design for multi-user mmWave MIMO system.

Modeling and simulation of hybrid beamforming design on multi-user mmWave MIMO systems using tools like MATLAB and NS-3 shall be done so as to develop and propose optimum precoder/combiner for improving the performance of the system. Result of existing and proposed work shall be compared to draw conclusive references.

4.1.3 Research procedure to develop an optimal Millimeter wave MIMO channel estimation solution for multi-cell multi-user scenario.

Modeling and simulation of various channel estimation methods on multi-cell hybrid mmWave MIMO systems using tools like MATLAB and NS-3 and analyze the impact of pilot contamination to system performance, so as to develop and propose optimum channel estimation technique for improving the performance of the multi-cell multi-user system. Result of existing and proposed work shall be compared to draw conclusive references.

4.1.4 Research procedure for performance of Non-orthogonal multiple access (NOMA) in Millimeter Wave communication.

Modeling of NOMA and OMA in an mmWave cell and simulate 5G network using network Millimeter wave module in NS-3 or LTE system toolbox in MATLAB so as to develop and propose an optimum model that can support different profile of users/devices. Result of existing and proposed work shall be compared to draw conclusive references.

4.2 Tools:

We studied various tools to identify available platform for performing the various experiments and evaluate outputs, that help us to reach a certain conclusion. There are various products or tools available for performance analysis of 5G such as MATLAB, Sci-lab and GNU Octave are a high-level interpreted language, primarily intended for numerical computations. For proposed research work, we will prefer MATLAB and few modules of NS3 (NS3.28) like millimetre-Wave, Spectrum Model, Propagation Model of Wireless and Network Module.

REFERENCES

[1] Cisco, “Cisco visual networking index, forcast and methodology 2016-2021,” Technical Report, 2018 [online].

[2] IEEE, “IEEE 5th generation and beyond technology roadmap white paper,” Technical Report, 2018 [online].

[3] A. Ossciaran, F. Boocardi, V. Barun, K. Kusume, P. Marsch, M. Maternia, O. Queseth and M. Schelllmann, “Scenarios for 5G mobile and wireless communications : the vision of the METIS project,” IEEE communication magazine, vol. 52, no. 05, pp. 26 -35, 2014.

[4] R. W. Heath, F. Boccardi, A. Lozano and T. L. Marzetta, “ Five disruptive technology directions for 5G,” IEEE communication magazine, vol. 52, no. 2, pp. 74 – 80, 2014.

[5] A. F. Molisch, M. Shafi, P. J. Smith, T. Haustein, P. Zhu, P. D. Silva and G. Wunder, “5G : A tutorial overview of standards, trials, challenges, deployment and practice,” IEEE Journal of selected areas communication, vol. 35, no. 06, pp. 1201-1221, 2017.

[6] ITU- R. M. 2083, “ IMT vision framework and overall objectives of the future development of IMT for 2020 and beyond,” 2015.

[7] E. Ayanoglu, A. L. Swindlehurst, P. Heydari, and F. Capolino, “Millimeter-wave massive MIMO: the next wireless revolution,” IEEE communication magazine, vol. 52, no.09, pp 56-62, 2014.

[8] M. Kamel, W. Hamouda and A. Youssef, “ Ultra dense networks : A survey,”

IEEE communication surveys tutorials, vol. 18, no. 04, pp. 2552- 2545, 2016.

[9] T. L. Marzetta, "Noncoperative cellular wireless with unlimited numbers of base station antennas, "IEEE transactions wireless communication, vol. 9, no. 11, pp. 2590- 3600, 2010.

[10] R.W. Heath, N.G. Prelcic and A.M. Sayeed, " An overview of signal processing techniques for millimeter wave MIMO systems," IEEE Journals of selected topics of signal processing, vol. 10, no. 3, pp. 436- 453, April 2016.

[11] X. Wang, L. Kong, F. Qiu and G. Chen, " Millimeter wave communication: A comprehensive survey," IEEE communication surveys and tutorials, vol. 20, no.3, pp. 1616-1653, Jun 2018.

[12] T. S. Rappaport, S. Sun, H. Zhao and F. Guiterrez, " Millimeter wave mobile communication for 5G cellular: it will work," vol. 1, no. 1, pp. 335- 349, May 2013.

[13] T. Bai, R.W. Heath and A. Alkhateeb, " Coverage and capacity of millimeter wave cellular networks, " IEEE communication magazine, vol. 52, no. 09, pp. 70-77, Sep. 2014.

[14] Z. Pi and F. Khan , " An introduction to millimeter wave mobile broadband systems," IEEE communication magazine, vol. 49, no.06, pp 101-107, 2011.

[15] J. Jing, C. Xiaoxue, and X. Yongbin, "Energy efficiency based downlink Multiuser hybrid beamforming for millimeter wave Massive MIMO system," The Journal of China Universities of Posts and Telecommunications, vol. 23, no. 4, pp. 53–62, Aug. 2016.

[16] J. Lee, G.T. Gil, and Y.H. Lee, "Channel estimation via orthogonal matching pursuit for hybrid MIMO systems in millimeter wave communication," IEEE transactions on communications, vol. 2,no. 05, pp. 01-17, Jun 2016.

[17] L. Zhao, D. W. Kwan, and J. Yuan, “Multiuser precoding and channel estimation for hybrid millimeter wave system,” IEEE Journal of selected area in communication, vol. 24,no. 1, pp. 1-16, Jun 2017.

[18] L. Zhao, Z. Wei, D. W. Kwan and J. Yuan, “Multicell hybrid millimeter wave systems: pilot contamination and interference mitigation,” IEEE transactions on communication, vol. 28,no. 4, pp. 1110-1128, Jun 2018.

[19] J. P. Coma, J. R. Fernandez, N. G. Prelcic and R. W. Heath, “Channel estimation and hybrid precoding for frequency selective multiuser millimeter wave MIMO systems” IEEE Journal of Selected Topics in Signal Processing, vol. 28, no. 1, pp. 1210–1226, Oct. 2018.

[20] R.W. Heath, A. Alkhateeb, G. Leu and S. Member, “Limited feedback hybrid precoding for multiuser millimeter wave systems,” IEEE transactions on wireless communications, vol. 14, no.11, pp. 6481-6495, Nov. 2015.

[21] T.E. Bogale and L.B. Le, “Massive MIMO and millimeter wave for 5G wireless Hetnet : potential and challenges”, IEEE vehicular technology magazine, vol. 11, no. 1, pp. 64–75, March 2016.

[22] S. A. R. Naqvi and S. A. Hassan, “Combining NOMA and millimeter Wave technology for cellular communication”, IEEE vehicular technology conf. (VTC-Fall 2016),2016.

[23] A. S. Marcano and H. L. Christiansen, “ Performance of Nonorthogonal multiple access (NOMA) in millimeter wave wireless communication for 5G networks,” Proceedings of 2017 international conference on computing, networking and communication IEEE, pp. 969-974, 2017.

[24] D. Zhang, Z. Zhou, C.Xu, Y. Zhang and T. Sato,“ Capacity analysis of NOMA with millimeter wave massive MIMO systems,” IEEE Journal of selected area in communication, vol. 35, no. 7, July 2017.

[25] L. Dai, B. Wang, Z. Wang and Y. Yuan, “ Nonorthogonal multiple access for 5G: solutions, challenges, opportunities and future research trends,” IEEE Communication Magazine, vol. 53, no. 09, pp. 74–81, Sep 2015.

[26] U. S. S. S. Arachchillage, D. N. K. Jayakody, S. K. Biswash and R. Dinis, “Recent advances and future research challenges in Nonorthogonal multiple Access for 5G networks,” IEEE 87th vehicular technology conference (VTC Spring), 2018.

[27] C. Sturm and W. Wiesbeck, “Waveform design and signal processing aspects for fusion of wireless communications and radar sensing,” Proc.IEEE, vol. 99, no. 7, pp. 1236–1259, July 2011.

[28] A. Pyattaev, K. Johnsson, S. Andreev, and Y. Koucheryavy, “Communication challenges in high-density deployments of wearable wireless devices,” IEEE Wireless Communication, vol. 22, no. 1, pp. 12–18, February 2015.

[29] A. Alkhateeb, M. Jianhua, N. Gonz´alez-Prelcic, and R. W. Heath Jr., “MIMO Precoding and combining solutions for millimetre - wave systems,” IEEE Communication Magazine, vol. 52, no. 12, pp. 122–131, Dec. 2014.

[30] J. Brady, N. Behdad, and A. M. Sayeed, “Beamspace MIMO for millimeter-wave communications: System architecture, modeling, analysis band measurements,” IEEE Trans. Antennas Propag., vol. 61, no. 7,pp. 3814–3827, July 2013.

[31] A. M. Sayeed and N. Behdad, “Continuous aperture phased MIMO: Basic theory and applications,” Proc. 2010 Annual Allerton Conference on Communications, Control and Computers, pp. 1196–1203, Sep. 2010.

[32] O. El Ayach, S. Rajagopal, S. Abu-Surra, Z. Pi, and R. W. Heath Jr., "Spatially sparse precoding in millimeter wave MIMO systems," IEEE Journals of Selected Areas Communication, vol. 13, no. 3, pp. 1499–1513, March 2014.

[33] A. Alkhateeb, O. El Ayach, G. Leus, and R. W. Heath Jr., "Channel estimation and hybrid precoding for millimeter wave cellular systems," and hybrid precoding IEEE Journals of Selected Topics Signal Processing, vol. 8, no. 5, pp. 831–846, Oct 2014.

[34] S. Han, C.-L. I, Z. Xu, and C. Rowell, "Large-scale antenna systems with hybrid analog and digital beamforming for millimeter wave 5G," IEEE Communication Magazine, vol. 53, no. 1, pp. 186–194, January 2015.

[35] J. G. Andrews, T. Bai, M. N. Kulkarni, A. Alkhateeb, A. K. Gupta, and R. W. Heath, "Modeling and analyzing millimetre wave cellular systems," IEEE Transactions Communication, vol. 65, no. 1, pp. 403–430, Jan. 2017.

[36] S. Hur et al., "Proposal on millimeter-wave channel modeling for 5G cellular system," IEEE Journals of Selected topics of Signal Processing, vol. 10, no. 3, pp. 454–469, Apr. 2016.

[37] T. S. Rappaport, G. R. MacCartney, S. Sun, H. Yan, and S. Deng, "Small-scale, local area, and transitional millimeter wave propagation for 5G communications," IEEE Transactions on Antennas Propagation, vol. 65, no. 12,pp. 6474–6490, Dec. 2017.

[38] L. Dai, B. Wang, M. Peng and S. Chen, "Hybrid precoding - based miliimeter wave massive MIMO-NOMA with simultaneous wireless information and power transfer," IEEE Journal of selected area in communication, vol. 37, no. 01, Jan. 2019.